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Frictional Contact Numerical Models for Numerous Collections of Rigid or Deformable Bodies

F. Dubois*, M. Jean[†]

*Laboratoire de Mécanique et Génie Civil, CNRS, USTL
cc 048 Place E. Bataillon, 34095 Montpellier cedex 05, France
dubois@lmgc.univ-montp2.fr

[†]Laboratoire de Mécanique et d'Acoustique, CNRS
31 chemin J. Aiguier, 13402 Marseille, France
mjean.recherche@wanadoo.fr

ABSTRACT

Interactions between contacting bodies may be physically quite complicated. Deriving a relevant numerical model for dynamical problem raises many issues especially due to the fact that it mixes various time and space scales. The numerical modelling, i.e. the writing of an interaction law and the choice of a numerical strategy, depends on the problem into consideration and what are the main results expected from a numerical simulation.

Primary phenomena are impenetrability of materials and dry friction. Other phenomena like cohesive behaviour, local deformability, plastic behaviour, viscous friction, wear, etc. should be taken into account.

Large collections of bodies, like granular materials, have their own specificities :

- the number of contacts may be very large, 1000 for small samples to 300.000 for “representative” samples;
- dynamics is to be taken into account since the motion equations governing the grains suppose they are free to move; meanwhile they are submitted to stiff interaction laws;
- simultaneous contacts are occurring;
- the solutions may suffer from indetermination; in rigid bodies collections, an equilibrium state might be realized by an infinity of combinations of reactions belonging to some subset. Coulomb's law is responsible for this non uniqueness.

Roughly, there are two numerical strategies :

- (SCD) The interaction laws are described by mappings relating the main local unknowns involved in the contact - the gap, the relative velocity, and the dual variable, the reaction (a force or an impulse). One ends up with a stiff ordinary differential equation which may be treated with an explicit integration scheme. Small time steps are necessary, together with some kind of damping ensuring the scheme stability. The episodes of contact are finely described. The so called Distinct Element Method (P. Cundall & al.) or the Molecular Dynamics methods belong to this *Smooth Contact Dynamics* (SCD) class.

- (NSCD) The interaction laws are described by Signorini condition and Coulomb's law, or other so called "derived laws". These laws are written as multi mappings relating the local unknowns, in the frame of Convex Analysis following J.J. Moreau, together with first order schemes for the dynamical equations. In the NSCD methods, at each contact, the impulse over the time step and the relative velocity at the end of the time step are computed together with the dynamical equation terms so as to satisfy Signorini condition and Coulomb's law. These impulses account for all events supposed to occur during a time step, free flights, action of external forces, single or numerous impacts between pairs or agglomerates of contacting bodies. Iterations must be performed in order to exhibit the values of the unknowns. The method allows large time steps. This is the *Non Smooth Contact Dynamics* (NSCD), a fully implicit method, initiated by J.J. Moreau [1], M. Jean [2] and implemented in the LMGC90 software by F. Dubois and M. Jean.

Several elementary examples illustrating the behaviour of the SCD and the NSCD method will be given concerning the impact of a few particles, using non smooth laws or spring damper contacting devices, using SCD or NSCD methods with small or large time steps: a bouncing ball, billiard balls, a chain of cohesive balls, etc.

It appears that indeed, explicit SCD methods give a fine description of the contact episode to be computed with small time steps. As far as large collections of bodies are concerned, coming into details of episodes of contact might be irrelevant or superfluous. For instance SCD methods generates genuine or artefact propagation of waves which are not of interest in a soil mechanic quasistatic experiment. Furthermore the mechanical values of the spring damper devices are hardly known. These devices should be understood as a smoothing or penalization process, the harder the springs, the smaller the time steps.

The implicit NSCD method uses large time steps and iterations are necessary in order to select a solution. The question of indetermination i.e. the fact that an equilibrium state of a sample may be realized by an infinity of combinations of reactions belonging to some subset, is raised in full rigid bodies models. This is illustrated by the example of a wedged disk and of the billiard balls. When the Signorini Coulomb interaction law is supplemented with a spring damper device, in the spirit of derived Signorini Coulomb's law (a smoother alternative way to comply with unilaterality) the indetermination is partly suppressed. Unfortunately it appears that those models suffer from sensitivity with respect to smoothing parameters, which exhibits a behaviour similar to indetermination. It seems that as far one is concerned with average data as stresses, resulting pressures on walls, or statistic distributions of forces, these indeterminations do not matter much because they hit mainly the weak forces.

References

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